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NON-DESTRUCTIVE STRESS MEASUREMENT OF CIVIL STRUCTURAL STEEL USING MAGNETIC ANISOTROPY SENSOR

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ABSTRACT

Recently, non-destructive stress measurement method using magnetic anisotropy sensor has been applied to the construction site such as steel bridges and steel pipes. In addition, steel rib used in the tunnel construction site was found to be possible to measure the stress by non-destructive method. In this study, steel loading experiments using magnetic anisotropy sensor and strain gauges were conducted to derive stress sensitivity curve for general structural rolled steel SS400 that is commonly used in civil engineering structures. As a result of laboratory experiments, stress sensitivity curves for general structural rolled steel SS400 were derived using output voltage measured by magnetic anisotropy sensor and average of stress measured by strain gauges depending on the measurement location. In addition, for the field application test of the magnetic anisotropy sensor, field experiments were conducted for the two most loaded places, H-pile and inclined struts, in the temporary structure of the construction sites. The field experiment results show a similar trend in the measured values by the magnetic anisotropy sensor and by the strain gauge, with an error of about 10% between the two methods, which is a sufficient resolution for engineering compared with the yield strength of general steels.

KEYWORDS: Magnetic Anisotropy Sensor, Non-Destructive, Stress Measurement, Civil Structural Steel, Temporary Structure

Original Article

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INTRODUCTION

As steel materials mainly used for civil structure is installed after completion of rolling, cooling and bending processing, in case of each steel structure, residual stress is included. In order to evaluate soundness of steel structure, confirmation of stress history and its condition including residual stress is very important. There are several methods in measuring steel material stress and residual stress but when mainly dividing it into two categories, it is a method of measuring stress by strain gauge and other method of non-destructive stress measurement using X-ray, ultrasonic and magnetostriction effect. As the former could perform high-precision measurement, it is widely used but it has a difficulty of having to measure stress by attaching strain gauge in advance under the condition that stress by external force or residual stress is not applied. On the other hand, the latter is very useful not only for measuring stress of structures having been constructed long time ago but also for measuring residual stress.

In this study, laboratory experiment and field experiment were performed by using magnetic anisotropy sensor that was developed for non-destructive stress measurement of steel material and after comparatively analyzing its result, applicability of magnetic anisotropy sensor to temporary H-beam structure was evaluated.

MAGNETIC ANISOTROPY SENSOR

Stress measurement system using magnetostriction effect has been researched continuously in order to measure residual stress of machinery and automobile components from 1960s up to the present and Toshinaga et al., (1977) measured residual stress of welding surroundings and structures by developing a sensor called stress tester. They made stress testers, one for compensation and the other for measurement by winding copper wire around two ㄷ shaped iron cores and measured stress by sensing and measuring stress through stress tester when magnetic permeability is changed by stress of measuring object. From the late 1970s, Abuku (1975) researched and developed magnetic anisotropy sensor that is considered to be most useful among magnetic sensors. Contrary to stress tester invented by Yosinaga, magnetic anisotropy sensor does not require tester for compensation and residual stress is measured by using magnetic anisotropy when measuring object represents it by stress. From the beginning of 1980s, Kashiwaya et al., (1985) removed magnetic hysteresis by stress by inventing demagnetization method and developed stress measurement method without considering an effect of lift-off. Recently, in construction field, stress measurement technique using magnetic anisotropy sensor has been used in steel bridge or steel pipe and it was clarified that it could be also applied to site measurement of steel H-beam used in tunnel construction site (Akutagawa et al., 2003; Sakai et al., 2000).

Measurement Principle of Magnetic Anisotropy Sensor

When magnetizing ferromagnetic substance, its length is slightly changed to the direction of magnetic circuit depending on strength of magnetic field and this length change is called magnetostriction and magnetostriction for length is transformed in parallel with magnetized direction. Features of magnetostriction is changed depending on material and when magnetostriction is extended to the magnetized direction, it is called as positive magnetostriction and if it is reduced to magnetized direction, it is called as negative magnetostriction.When steel material like iron is magnetized, a positive magnetostriction is occurred. In other words, when tensile stress is taken place to steel material, magnetic permeability is improved as magnetostriction is extended to magnetized direction and in order to measure this magnetic permeability change, magnetic anisotropy sensor is utilized.

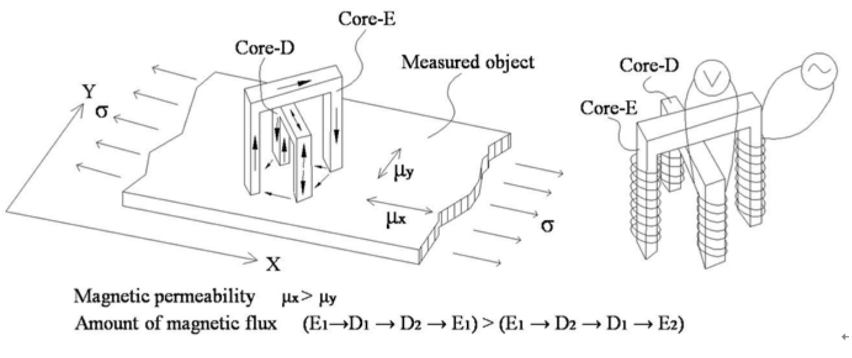


Figure 1: Measurement Principles of Magnetic Anisotropy Sensor

This sensor includes diversified types and a sensor applied in this study is quadruped cylindrical type (Φ=20mm, H=30mm) and on diagonal line of quadruped leg, output coil (Core-D) and input coil (Core-E) are wound respectively. Considering stress condition as shown on Figure 1, in case of magnetic permeability of measuring object. as that of x direction (μ_x) gets bigger than that of y direction (μ_y), when current is flowed to input coil (Core-E), most of magnetic flux coming from E_1 is directly flowed to E_2 in the shortest distance but due to difference of magnetic permeability (μ_{x} - μ_y),

induced current is flowed in output coil (Core-D) from E_1 to D_1, D_2 like arrow direction and then voltage is taken place.

Composition of Measurement System of Magnetic Anisotropy Sensor

Magnetic anisotropy sensor is composed of measurement probe and measurement system. Measurement probe is covered with plastic protection cap in order to remove noise by winding coil to quadruped cylindrical pure iron. And measurement system could be mainly divided into input module and output module. Input module is a part that supplies power to probe and circuit and output module is a part of display so that tester could read through filtering after amplifying detected voltage. Figure 2 shows block diagram of measurement system of magnetic anisotropy sensor.

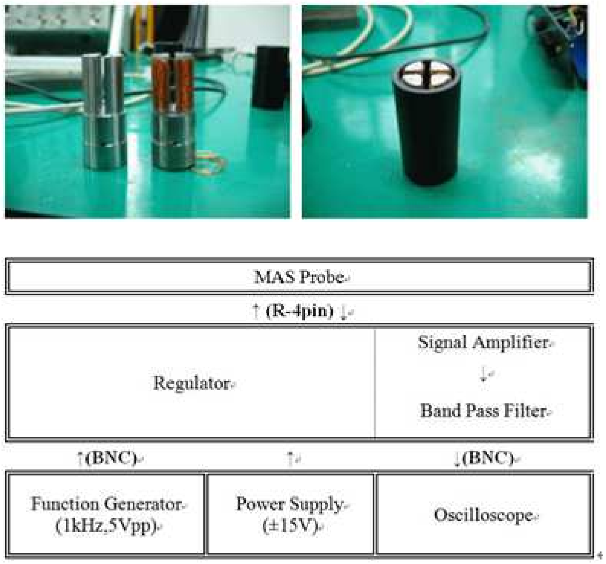


Figure 2: Magnetic Anisotropy Sensor Probe and Measurement System Block Diagram

LABORATORY EXPERIMENT

Steel Plate Loading Test

As test piece for a test, SS400 that is rolled steel for general structure manufactured locally was used and two test pieces were manufactured equally and same test was performed by dividing it into thermal treated test piece (annealing) and not thermal treated (non-annealing) test piece. Specification and chemical composition of test piece are as shown on Table 1. Loading was applied to 2 points (left, right side) distanced from the central point of test piece by 150mm and at loading stage, as measurable region is limited to elastic region, loading was applied in the order of 0kN, 5kN, 10kN, 15kN, 20kN by setting maximum loading as 20kN. In a process of test, stress was measured by using 2-axis electric resistance type strain gauge and output voltage was measured by magnetic anisotropy sensor. Measurement position of strain gauge (S/G) and magnetic anisotropy sensor (MAS) was installed by turns based on space of 25mm from central point as shown on Figure 3.

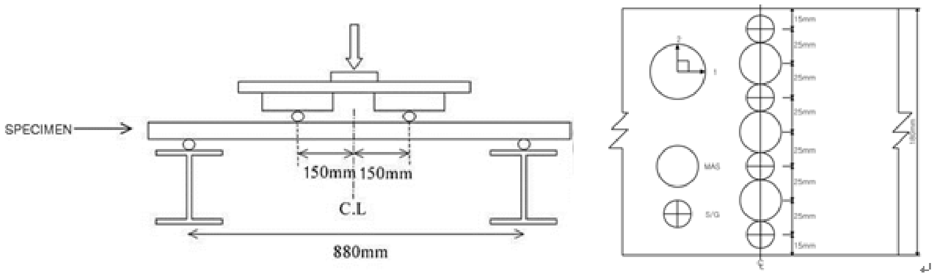


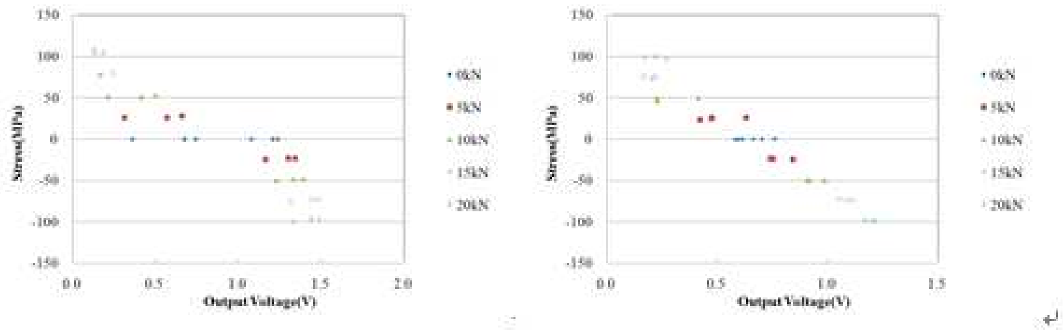
Figure 3: Experimental Schematic of Steel Plate Loading

Table 1: Specification and Chemical Composition of the Specimen

Specification						
Size	(L)1,000 ㎜×(B)180 ㎜×(T)28 ㎜					
Type	SS400(Yield strength : 245MPa, Tensile strength : 425MPa, Elongation:23%)					
Chemical composition(%)						
C	Si	Mn	P	S	Alt	B
0.18	0.02	0.81	0.011	0.006	0.025	0.0016

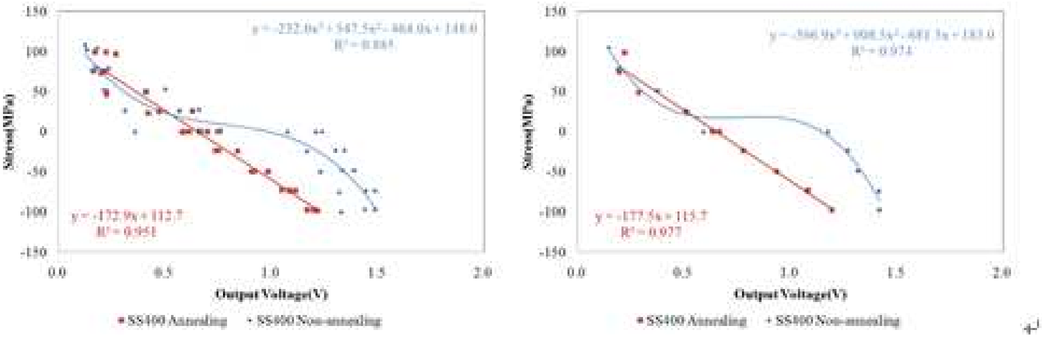
Result of Steel Plate Loading Test and Its Analysis

As shown on Figure 4, as a result of loading test of steel plate, in order to deduce a correlation between stress measured by strain gauge and output voltage measured by magnetic anisotropy sensor, average value of strain gauge at left, right side of magnetic anisotropy sensor was compared with output voltage of magnetic anisotropy sensor. In Figure 5(a), a regression analysis was performed for output voltage of magnetic anisotropy sensor and stress of strain gauge and its correlation was analyzed and in Figure 5(b), regression analysis was performed by using output voltage of magnetic anisotropy sensor and average of stress of strain gauge.



(a) SS400, Non-Annealing (b) SS400, Annealing

Figure 4: Distribution of Stress VS. Output Voltage According to the Load Step



(a) Stress vs Output Voltage (b) Average Stress vs. Output Voltage

Figure 5: Correlation of Stress vs. Output Voltage

By changing analysis technique based on the result of steel plate loading test, stress variation of strain gauge and that of output voltage of magnetic anisotropy sensor at each loading stage were comparatively analyzed. It could be realized that when residual stress is not considered, that is, when leaving output voltage of magnetic anisotropy sensor measured at unloaded member as resetting value, output voltage variation and stress change of strain gauge being changed depending on each loading stage showed a lineal relation as shown on Figure 6.

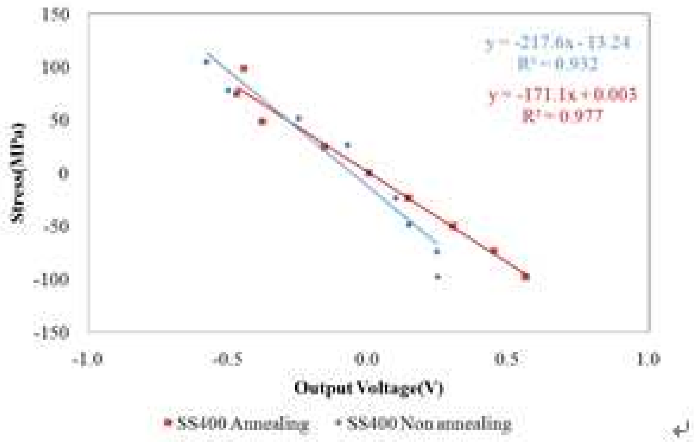


Figure 6: Correlation of Stress Variation vs. Output Voltage Variation

Measurement Possibility Review of Residual Stress using Magnetic Anisotropy Sensor

In order to identify whether magnetic anisotropy sensor could measure residual stress, thermal treatment (annealing) of steel material was performed. For comparison, 4-directional measurement was performed for test piece under dead load by using magnetic anisotropy sensor and for the direction showing the biggest output voltage, output voltage before, after annealing was compared. Figure 7 shows difference of output voltage by each measurement position before, after annealing. In measurement probe of magnetic anisotropy sensor, measured basic output voltage was represented as app. 500-520mV and while output voltage measured in test piece without annealing processing shows a difference of app.300-1200mV, that measured in test piece with annealing processing shows app. 300-700mV. This implies that residual stress of test piece was removed over a certain degree by annealing processing.

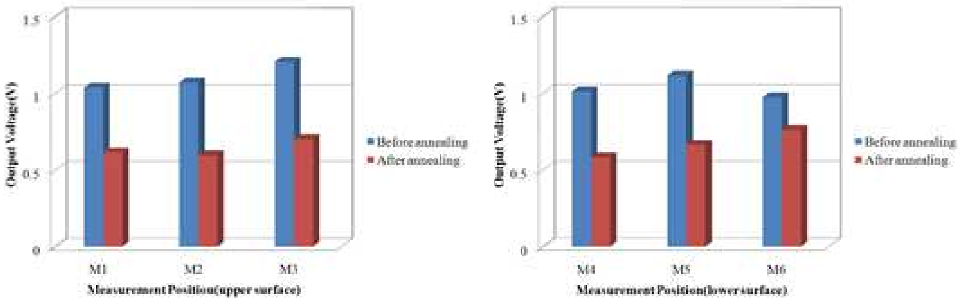


Figure 7: output Voltage Change by Annealing

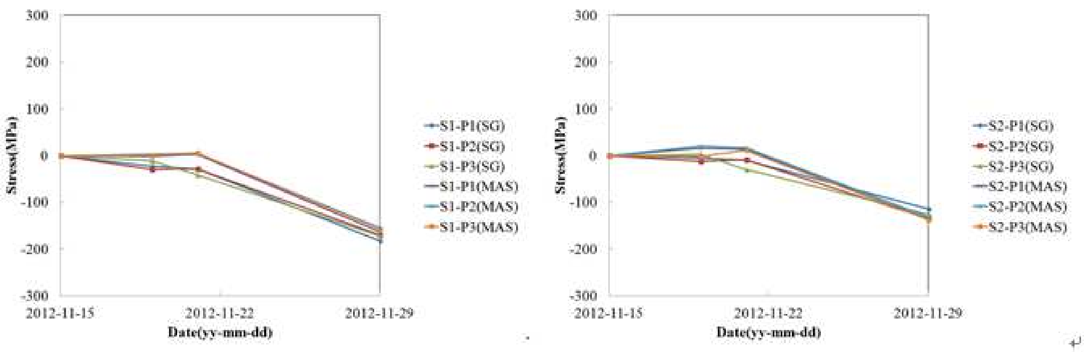
EVALUATION OF FIELD APPLICABILITY

Field Experiment

In order to perform non-destructive stress measurement of steel material for civil structure using magnetic anisotropy sensor, field experiment was performed at one temporary facility of civil construction site located at Youngdeok-gun, Gyeongbuk of Korea. Temporary construction method of target site was H-pile+earth wall and steel type of H-pile was SS400 that is identical with laboratory experiment. Construction status was that excavation was progressed by app. 2m at the time of installing early measuring sensor and after installing sensor, excavation was performed by app. 2m additionally. As shown on Figure 8, field experiment was performed by using strain gauge and magnetic anisotropy sensor at two places of H-pile and inclined struts that receive the most heavy load in temporary facility of target site.

Figure 8: Foreground of On-Site Status and Field Measurement

Result of Field Experiment



(a) Inclined Struts Measurement Results **(b) H- Pile Measurement Results**

Figure 9: Measurement Results Comparison of Strain Gauge and Magnetic Anisotropy Sensor

As a result of field experiment using magnetic anisotropy sensor, as shown on Figure 9, measurement value of strain gauge and that of magnetic anisotropy sensor show similar tendency and error of magnetic anisotropy sensor was app. 10% compared with that of strain gauge.

CONCLUSIONS

In this study, a test for applicability of magnetic anisotropy sensor was performed in order to measure non-destructive stress of steel material for civil structure.First, steel material loading test for SS400 that is universally used for civil structure by using magnetic anisotropy sensor and strain gauge was performed.As a result of laboratory experiment, it could be realized that when residual stress is not considered, that is, when leaving output voltage of magnetic anisotropy sensor measured at unloaded member as resetting value, output voltage variation and stress change of strain gauge being changed depending on each loading stage showed a lineal relation. In addition, for the field application test of the magnetic anisotropy sensor, field experiments were conducted for the two most loaded places, H-pile and inclined struts, in the temporary structure of the construction sites. The field experiment results show a similar trend in the measured values by the magnetic anisotropy sensor and by the strain gauge, with an error of about 10% between the two methods, which is a sufficient resolution for engineering compared with the yield strength of general steels.

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